



Search for the Higgs boson decaying to b-quark pairs in the ATLAS experiment

Patricia Conde Muíño
on behalf of the ATLAS Collaboration



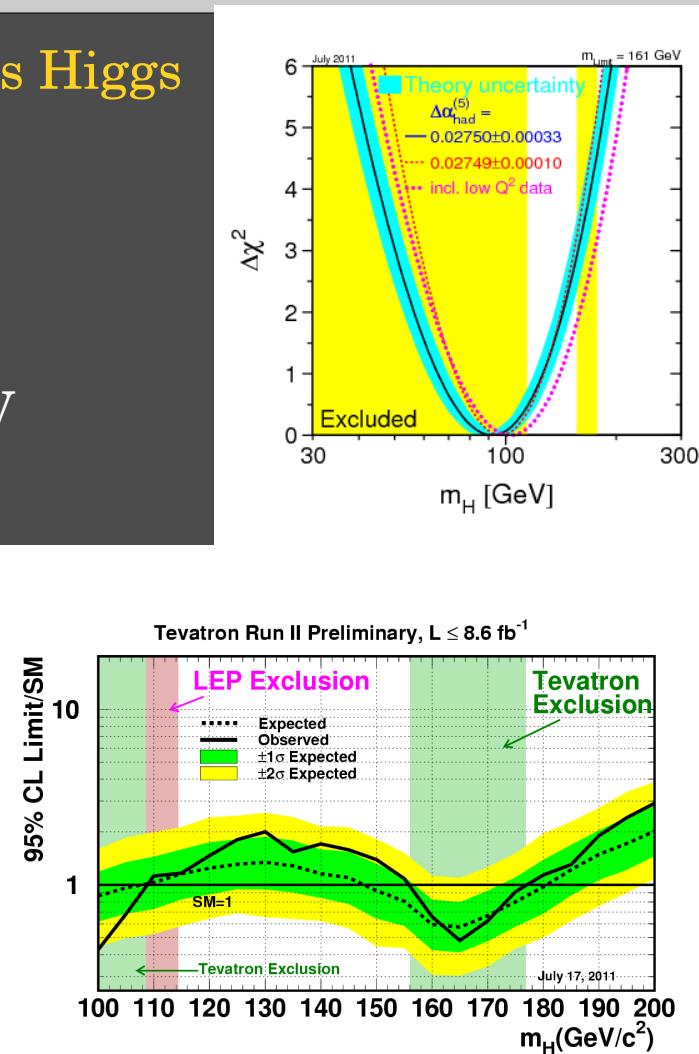
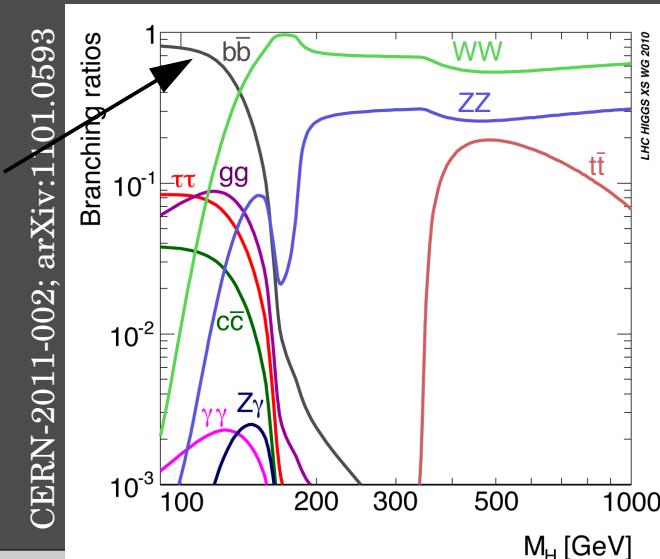
Low mass Higgs

Fits to the Standard Model favor a low mass Higgs

- Current exclusion limits @ 95% CL
 - LEP excludes $m_H < 114.4$ GeV
 - Tevatron excludes $156 < m_H < 177$ GeV
 - ATLAS+CMS exclude $145 < m_H < 466$ GeV
- EW fit: $m_H = 92^{+34}_{-26}$ GeV

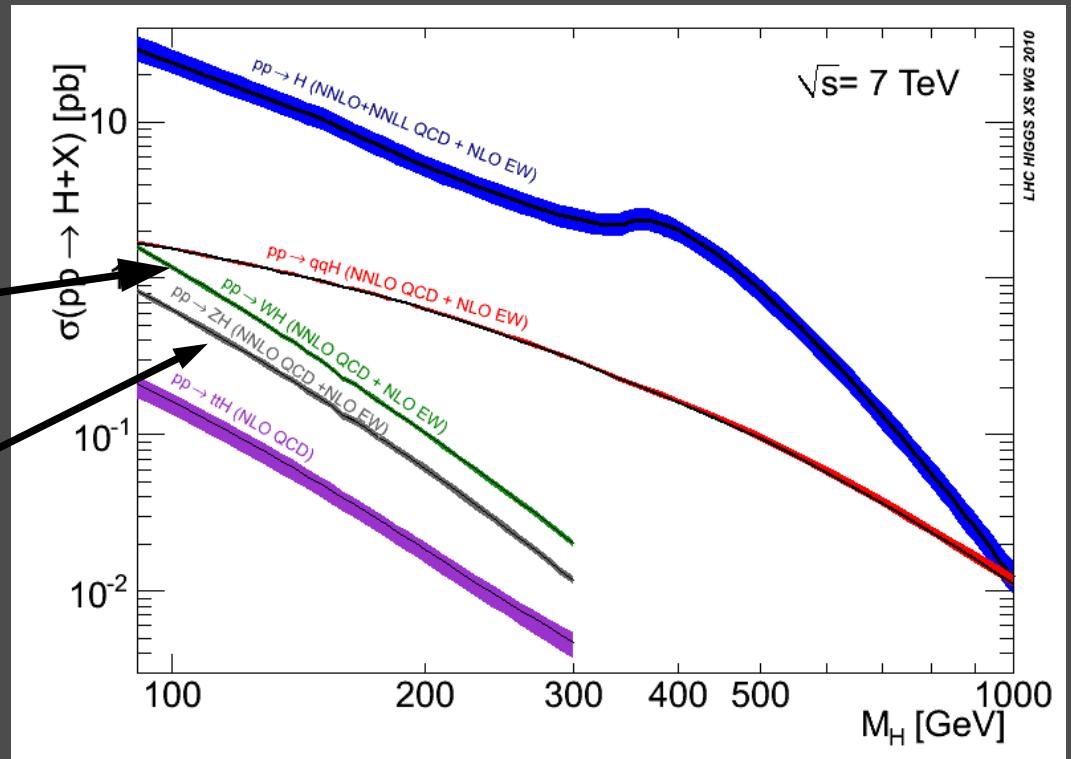
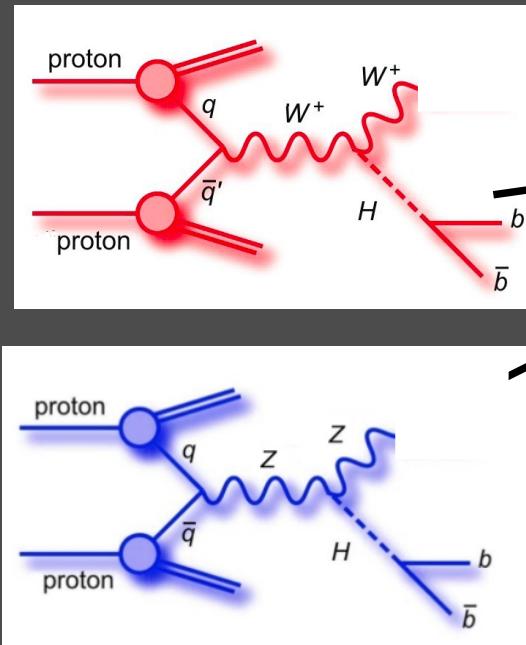
In this low mass range, the $H \rightarrow bb$ decay mode dominates

- Enhanced in some SUSY models



Higgs to b-quark pairs

- gg \rightarrow H dominates but has huge SM background

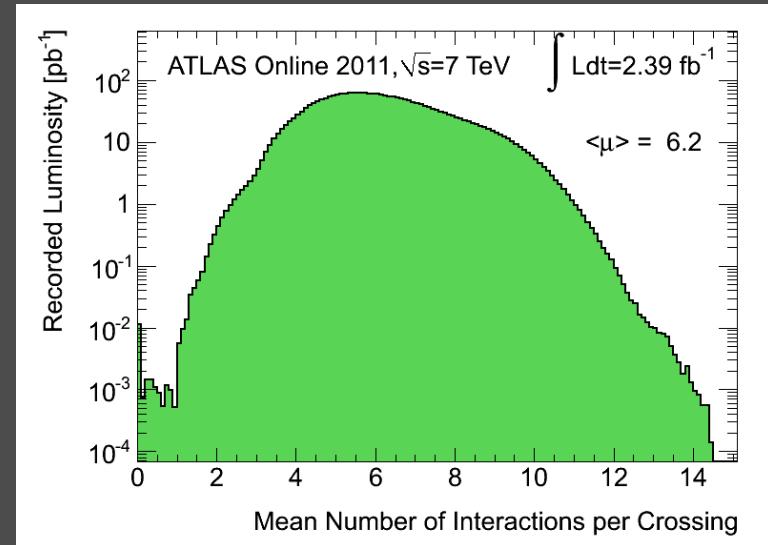
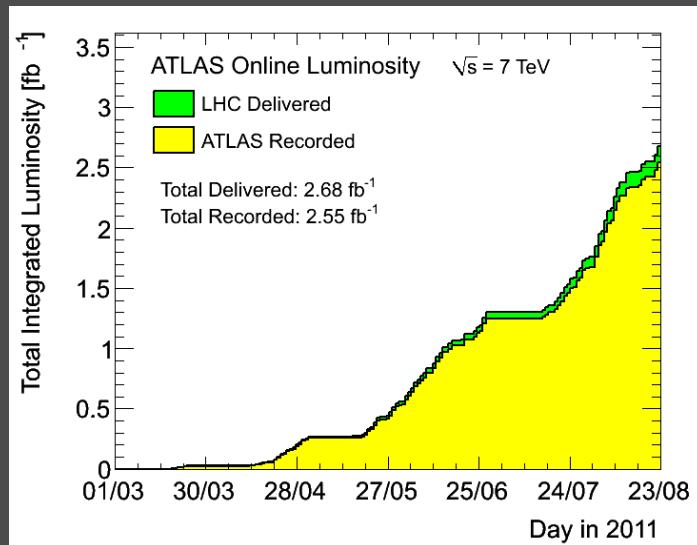


- VH has lower cross section but clean signatures

ATLAS has searched for the SM H \rightarrow bb in VH associated production

2011 data taking

- Integrated luminosity: 2.55 fb^{-1} recorded at ATLAS
 - Luminosity used in the $H \rightarrow bb$ analysis: 1.04 fb^{-1}
- Peak luminosity: $2.37 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$
- Average pile-up: $\langle \mu \rangle = 6.2$
- Continue run till end 2012. Then shutdown for upgrade





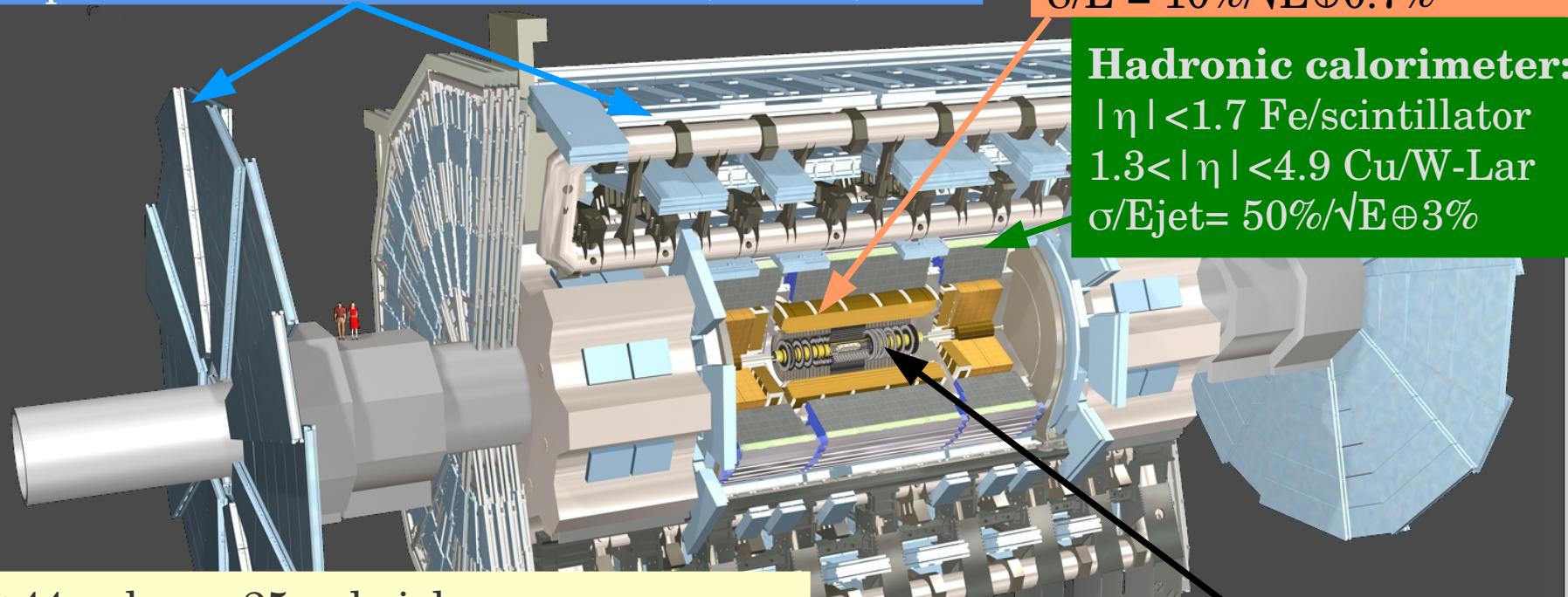
The ATLAS detector

Muon Spectrometer: $|\eta| < 2.7$

Air-core toroids and gas-based muon chambers
 $\sigma/pT = 2\% @ 50\text{GeV}$ to $10\% @ 1\text{TeV}$ (ID+MS)

EM calorimeter: $|\eta| < 3.2$
Pb-LAr Accordion
 $\sigma/E = 10\%/\sqrt{E} \oplus 0.7\%$

Hadronic calorimeter:
 $|\eta| < 1.7$ Fe/scintillator
 $1.3 < |\eta| < 4.9$ Cu/W-Lar
 $\sigma/E_{jet} = 50\%/\sqrt{E} \oplus 3\%$



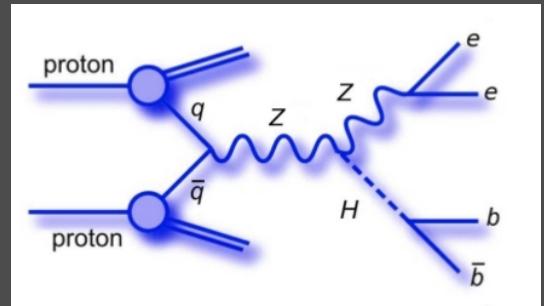
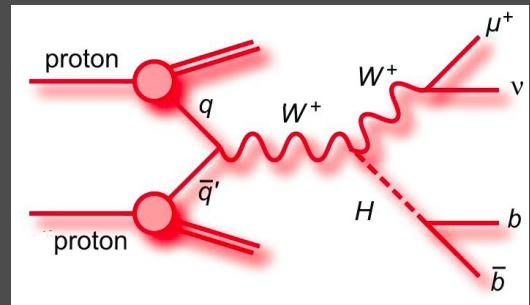
- › 44 m long, 25 m height
- › $\approx 10^8$ electronic channels
- › 3-level trigger reducing 40 MHz collision rate to 300 Hz of events to tape

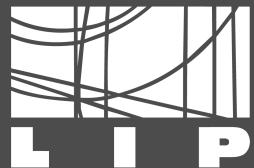
Inner Tracker: $|\eta| < 2.5$, $B=2\text{T}$
Si pixels/strips and Trans. Rad. Det.
 $\sigma/pT = 0.05\% pT (\text{GeV}) \oplus 1\%$



VH search at ATLAS

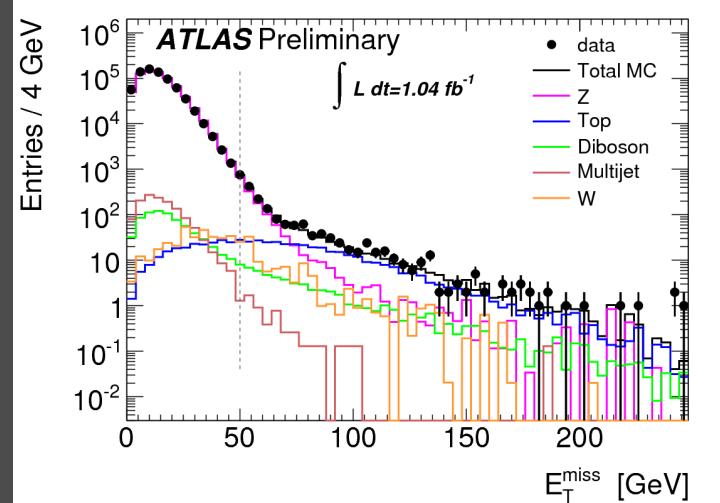
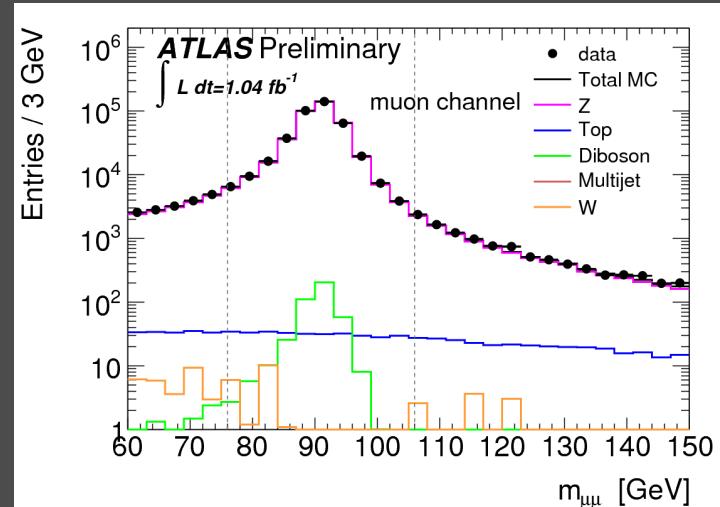
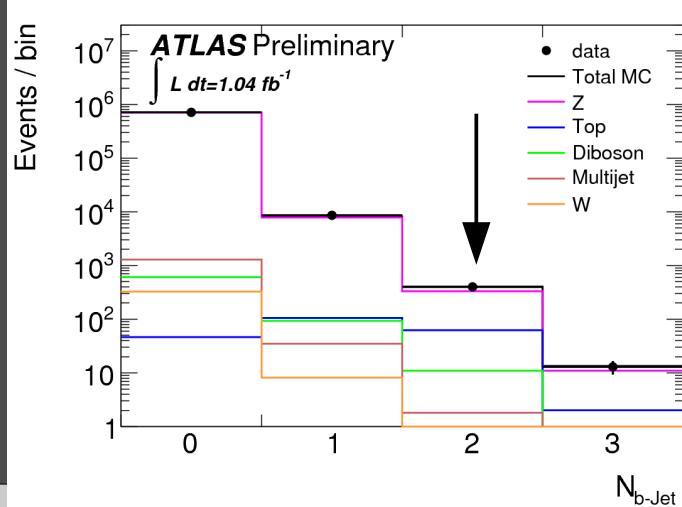
- Simple but robust cut based analysis
- Search channels:
 - $\text{pp} \rightarrow \text{WH} \rightarrow l\nu b\bar{b}$
 - $\text{pp} \rightarrow \text{ZH} \rightarrow ll b\bar{b}$
- Clean signatures:
 - High p_T isolated leptons
 - Two b-jets
 - E_T^{miss} in the WH channel
- SM backgrounds:
 - W/Z+jets
 - QCD multijet production
 - $\sigma_{\text{WH}} \approx 2x\sigma_{\text{ZH}}$ but ZH less affected by top background
 - Top quark production
 - Di-boson production: WZ, WW, ZZ





ZH → ll bb selection

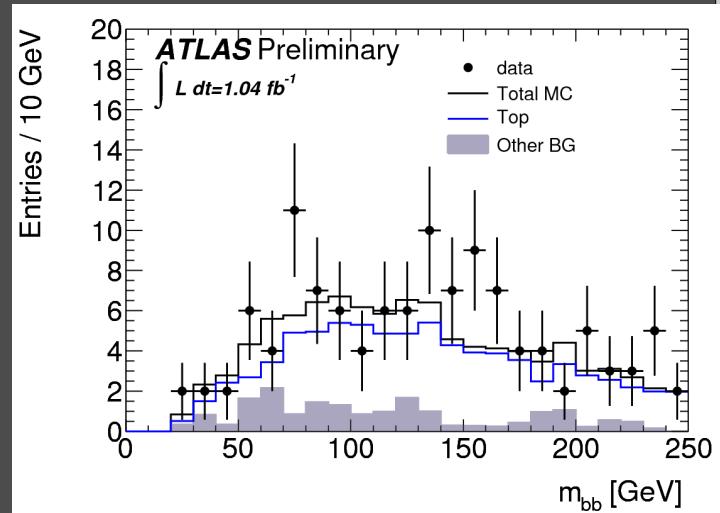
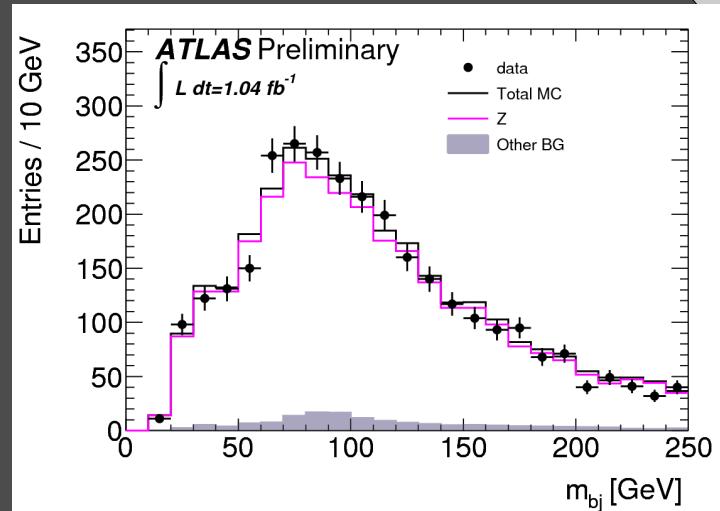
- Trigger:
 - e ($p_T^e > 20$ GeV) or μ ($p_T^\mu > 18$ GeV)
 - $2e/2\mu$ trigger ($p_T^l > 12$ GeV)
- Exactly 2 leptons $p_T > 20$ GeV
- Z mass cut: $76 < m_{ll} < 106$ GeV
- $E_T^{\text{miss}} < 50$ GeV
- Two leading jets b-tagged





ZH → ll bb background estimation

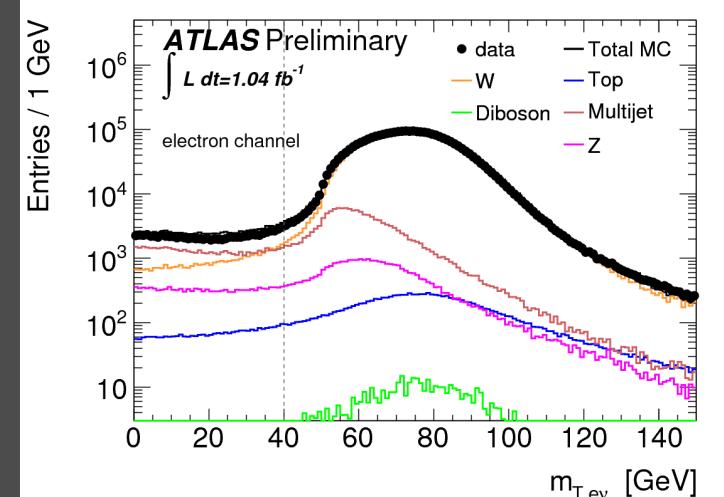
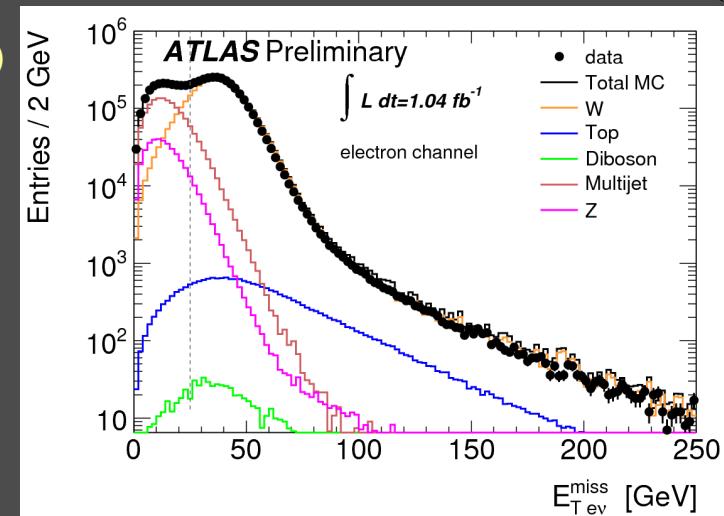
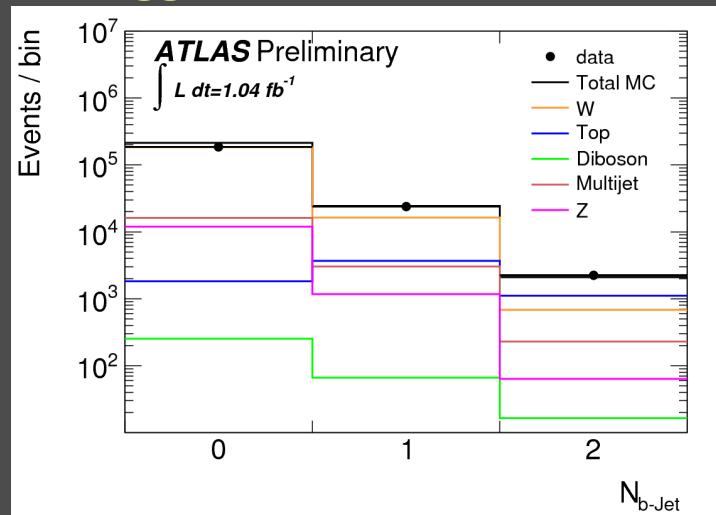
- Zbb:
 - Shape from MC
 - Normalization: fit to $m_{bb} < 80$ GeV
 - Control region: events with only one b-tagged jet
- Top production:
 - Taken from MC simulation
 - Top control region: m_{ll} side bands
- QCD multijet events:
 - Shape: use a multijet enriched sample
 - Normalization: multicompoment fit to m_{ll}
- Diboson production: from MC simulation





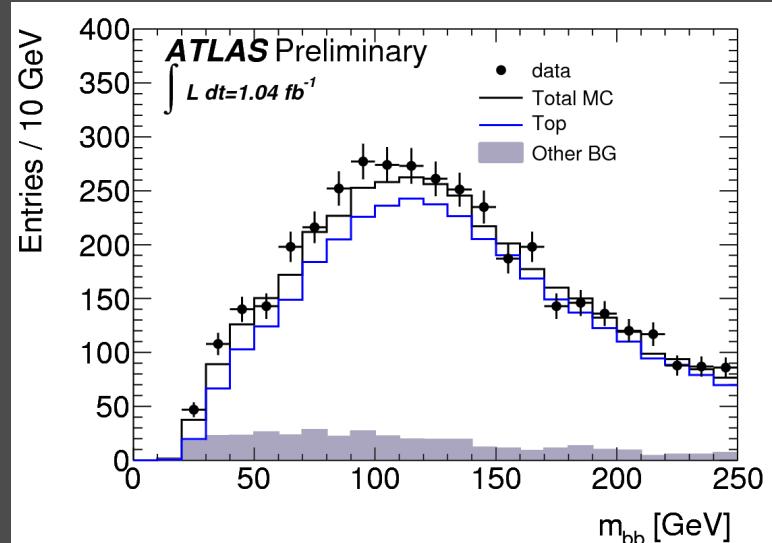
WH $\rightarrow l\nu$ bb selection

- Trigger: e ($p_T^e > 20 \text{ GeV}$) or μ ($p_T^\mu > 18 \text{ GeV}$)
- Exactly 1 lepton with $p_T > 25 \text{ GeV}$
- $E_T^{\text{miss}} > 25 \text{ GeV}$
- $M_T = [2p_T^l p_T^v (1 - \cos \Delta\phi_{lv})]^{1/2} > 40 \text{ GeV}$
- Exactly 2 jets (anti- k_T 0.4; $E_T > 25 \text{ GeV}$)
- Both jets b-tagged



WH $\rightarrow l\nu$ bb background estimation

- Top production:
 - Shape from MC simulation
 - Normalization: fit m_{bb} sidebands ($m_{bb} < 80$ GeV, $140 < m_{bb} < 250$ GeV)
 - Control region: events with 3 jets
- Wbb:
 - Shape: use m_{jj} to model m_{bb}
 - Normalization: fit to $m_{bb} < 80$ GeV
- QCD multijet events:
 - Shape: use a multijet enriched data sample
 - Normalization from multicomponent fit to E_T^{miss}
- Di-boson production: estimated from MC

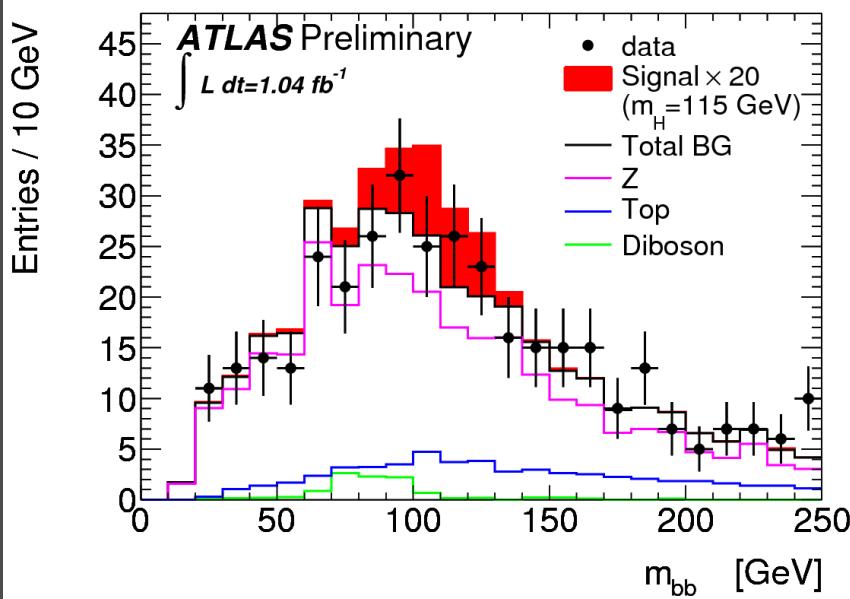


Systematic uncertainties

- Dominant systematic uncertainty comes from b-tagging efficiency (16-17%)
- Followed by jet energy scale (up to 9%)

Source of Uncertainty	Effect on $ZH \rightarrow \ell\ell b\bar{b}$ signal		Effect on $WH \rightarrow \ell v b\bar{b}$ signal	
	$m_H = 115$ GeV	$m_H = 130$ GeV	$m_H = 115$ GeV	$m_H = 130$ GeV
Electron Energy Scale	< 1%	< 1%	1%	1%
Electron Energy Resolution	< 1%	< 1%	1%	1%
Muon Momentum Resolution	1%	3%	4%	1%
Jet Energy	9%	7%	1%	3%
Jet Energy Resolution	< 1%	< 1%	1%	1%
Missing Transverse Energy	2%	2%	2%	3%
<i>b</i> -tagging Efficiency	16%	17%	16%	17%
<i>b</i> -tagging Mis-tag Fraction	< 1%	< 1%	3%	3%
Electron Efficiency	1%	1%	1%	1%
Muon Efficiency	1%	1%	1%	1%
Luminosity	4%	4%	4%	4%
Higgs Cross-section	5%	5%	5%	5%

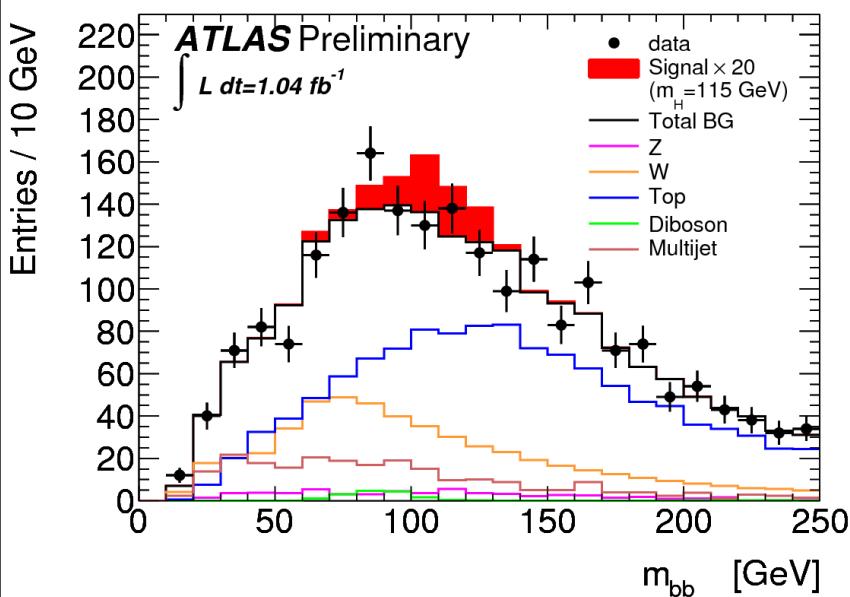
- The background expectation agrees well with the data
- No excess of events observed
- Dominated by systematic uncertainties



Source	expected events	(stat.)	(sys.)
Z+jets	261.0	\pm 7.8	\pm 24.6
Top-quark	52.0	\pm 1.3	\pm 10.6
Multijet	1.4	\pm 0.4	\pm 1.4
ZZ	9.2	\pm 1.1	\pm 2.3
WZ	1.1	\pm 0.3	\pm 0.3
Total background	324.7	\pm 8.0	\pm 27.9
Data	329		
Signal $m_H = 110 \text{ GeV}$	2.22	\pm 0.09	\pm 0.43
Signal $m_H = 115 \text{ GeV}$	1.91	\pm 0.07	\pm 0.38
Signal $m_H = 120 \text{ GeV}$	1.58	\pm 0.06	\pm 0.32
Signal $m_H = 125 \text{ GeV}$	1.44	\pm 0.05	\pm 0.28
Signal $m_H = 130 \text{ GeV}$	1.02	\pm 0.04	\pm 0.20

WH $\rightarrow l\nu bb$ results

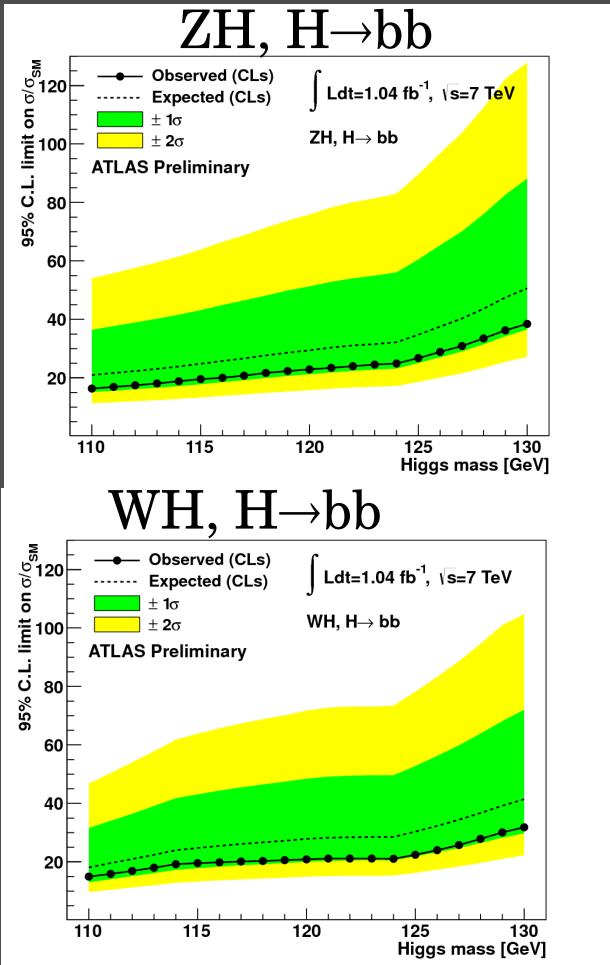
- The background expectation agrees well with the data
- No excess of events observed
- Dominated by systematic uncertainty



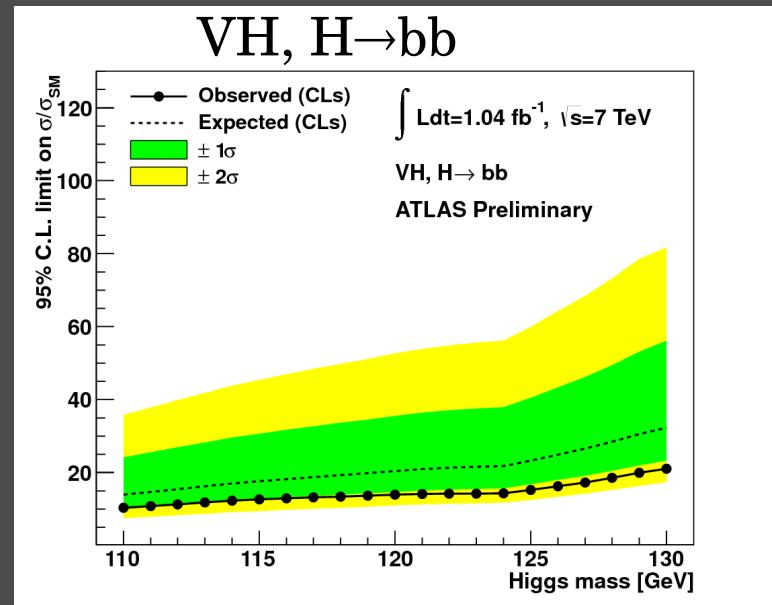
Source	expected			
	events	(stat.)	(sys.)	
Z+jets	54.4	\pm 3.9	\pm 12.3	
W+jets	466.7	\pm 1.4	\pm 66.5	
Top-quark	1141.8	\pm 8.8	\pm 78.0	
Multijet	193.0	\pm 9.4	\pm 96.5	
WZ	16.1	\pm 2.2	\pm 3.4	
WW	4.8	\pm 1.1	\pm 1.4	
Total background	1876.8	\pm 13.7	\pm 147.2	
Data	1888			
Signal $m_H = 110 \text{ GeV}$	6.72	\pm 0.31	\pm 1.20	
Signal $m_H = 115 \text{ GeV}$	5.25	\pm 0.30	\pm 0.97	
Signal $m_H = 120 \text{ GeV}$	4.54	\pm 0.25	\pm 0.83	
Signal $m_H = 125 \text{ GeV}$	4.08	\pm 0.21	\pm 0.77	
Signal $m_H = 130 \text{ GeV}$	3.28	\pm 0.17	\pm 0.62	

Exclusion limits

- Single channel exclusion limit between 15-35 \times SM cross section

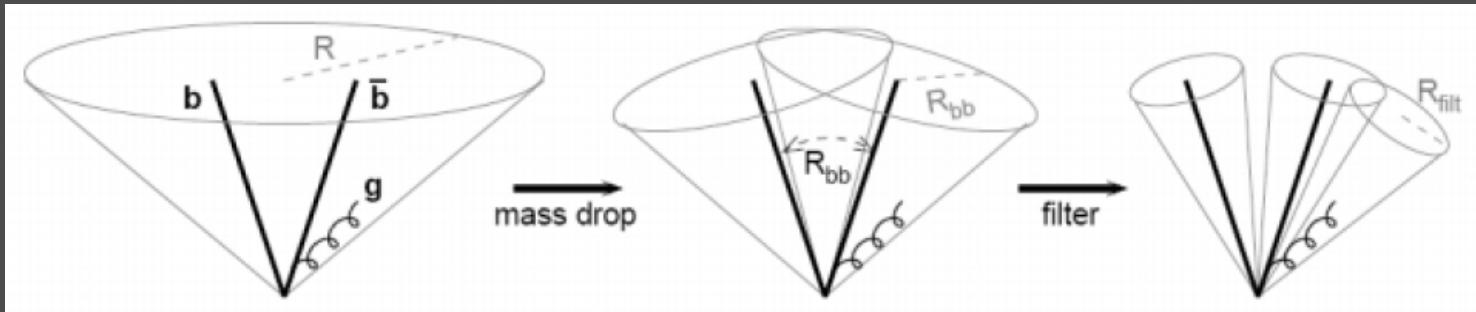


- Combined exclusion limit between 10-20 \times SM cross section for the mass range $110 < m_H < 130$ GeV



For the future: boosted H \rightarrow bb

- Alternative procedure: search for high p_T Higgs to a b-quark pair
- Higgs $p_T > 200$ GeV
 - 5% signal acceptance but larger decrease in backgrounds
- Select V events ($V=W,Z$ decaying leptonically) and search for a single H \rightarrow bb jet:
 - Search for a high p_T jet (Cambridge-Aachen algorithm, $R=1.2$)
 - Search jet clustering in reverse order to look for a large mass drop
 - Re-cluster with smaller R parameter to find sub-jets

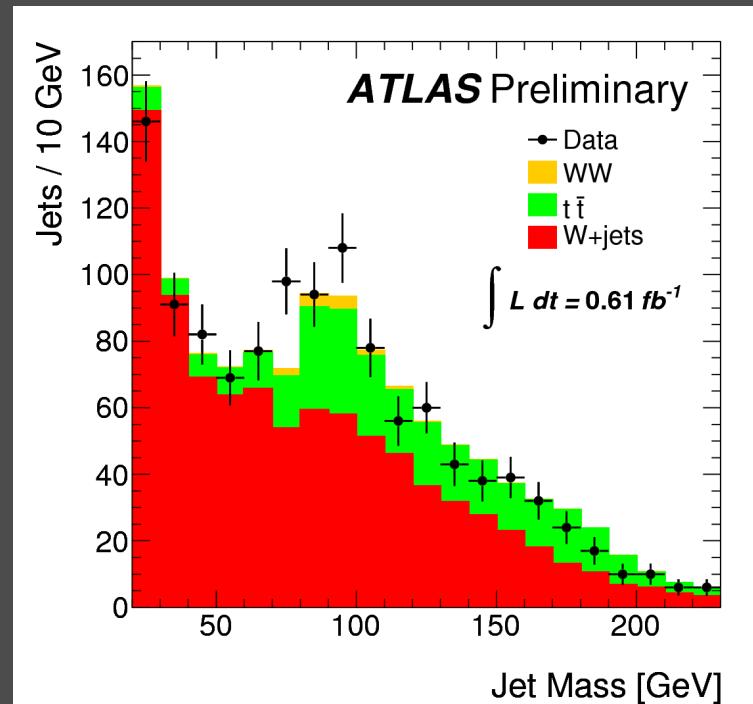


(Phys.Rev. Lett. 100(2008) 242001)

First boosted studies

- Select events consistent with $W \rightarrow l\nu + 1 \text{ jet}$, with $p_T^{\text{jet}} > 180 \text{ GeV}$ and $\Delta\phi^{W,\text{jet}} > 1.2$
 - Apply jet filtering (C/A, $R = 1.2$)
 - No b-tagging is applied
- $t\bar{t}$, $W+\text{jets}$, and SM WW processes included
- Peak consistent with $W \rightarrow jj$ in $t\bar{t}$ events

These first results are encouraging, promising new results with boosted jet substructure techniques in the near future





Conclusions

- First search for the SM $H \rightarrow bb$ at LHC in the associated production channels WH and ZH
- Combined exclusion limit at 95% CL between 10-20 x SM cross sections for m_H between 110 and 130 GeV
- Plenty of room for improvements
 - Lots of new data coming
 - Reduce systematic uncertainties
 - Use multivariate analysis techniques
 - Other channels to be explored
- Proof of principle for boosted Higgs searches

Reference: ATLAS-CONF-2011-103



Thank you!

Acknowledgements





Backup



Sources of systematic uncertainties

Source of Uncertainty	Treatment in analysis	
	ZH	WH
Luminosity	3.7%	3.7%
Higgs boson cross-section	5%	5%
Background norm. and shape:		
Top	9%	6%
$Z+jets$	9% plus shape	9%
$W+jets$	negligible	14% plus shapes
ZZ	11%	negligible
WZ	11%	11%
WW	negligible	11%
QCD multijets	100%	50%



Sources of systematic uncertainty (II)

Source of Uncertainty	Treatment in analysis
Jet Energy Scale (JES)	2 – 7% as a function of p_T and η
Jet Pile-up Uncertainty	2 – 7% as a function of p_T and η
b-quark Energy Scale	2.5%
Jet Energy Resolution	5 – 12%
Electron Selection Efficiency	0.7 – 3% as a function of p_T , 0.4 – 6% as a function of η
Electron Trigger Efficiency	0.4 – 1% as a function of η
Electron Reconstruction Efficiency	0.7 – 1.8% as a function of η
Electron Energy Scale	0.1 – 6% as a function of η , pileup, material effects etc.
Electron Energy Resolution	Sampling term 20%, a small constant term has a large variation with η
Muon Selection Efficiency	0.2 – 3% as a function of p_T
Muon Trigger Efficiency	< 1%
Muon Momentum Scale	2 – 16% η -dependent systematic on scale
Muon Momentum Resolution	p_T and η -dependent resolution smearing functions, systematic $\leq 1\%$
b -tagging Efficiency	5 – 14% as a function of p_T
b -tagging Mis-tag Fraction	8 – 12% as a function of p_T and η
Missing Transverse Energy	Add/subtract object uncertainties in E_T^{miss}